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METHOD FOR THE LASER TREATMENT OF SUBSURFACE BLOOD VESSELS

FIELD OF THE INVENTION

This invention relates to the field of laser dermatology and more particularly to a method for utilizing a laser to treat and selectively destroy blood vessels located at some depth below the surface of the skin.

RELATED APPLICATION

3/20/97 BKY

This application is a continuation in part of application serial number 08/022,978 filed February 24, 1993, now US Patent No. 5,527,350.

BACKGROUND OF THE INVENTION

There are many conditions that dermatologists are called upon to treat which involve, either directly or indirectly, blood vessels located in the dermal skin layer at depths of up to several millimeters from the skin surface, which conditions can be relieved or cured by coagulating the blood in such vessels resulting in the destruction thereof. Such conditions include, but are by no means limited to, visible leg veins including varicose veins, telangiectasias (i.e., vascular lesions formed by dilation of small blood vessels which may appear in many parts of the body including the face; port wine stains, unwanted hair and psoriasis. In the case of unwanted hair, blood vessels in the base of the hair follicle (i.e., in the papillary bulb) feed the follicle, and if these blood vessels can be destroyed, there is a possibility that the follicle will also be destroyed resulting in the permanent removal of the hair growing therefrom. Similarly, there is evidence that the destruction of blood vessels underlying psoriatic plaque can alleviate the symptoms of psoriasis.

However, lasers which have heretofore been used for destruction of blood vessels have normally operated at wavelengths of slightly below 600 nm. This is because the absorption coefficient for blood drops off sharply at 600 nm, dropping by roughly two orders of magnitude between 580 and 700 nm. However, because of the high absorption of blood at , for example, 577 nm, the typical wavelength used for selective photothermolysis on dermal tissue, absorption of light by hemoglobin in blood, and also by melanin in the skin which also is highly absorbent at these wavelengths, causes much of the incident light to be absorbed within a few hundred microns of the skin surface, preventing such radiation from reaching deep vessels at a sufficient level to cause coagulation thereof. The scattering coefficient for tissue is also relatively large at these wavelengths further reducing light energy reaching deep vessels. If the fluence of the laser is increased in an effort to get sufficient energy to the deep vessels at wavelengths shorter than about 700 nm, the high fluence or energy can cause explosion of surface vessels and/or burning of the skin.

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A need therefore exists for an improved method for treating dermatological conditions by destroying deep blood vessels, and in particular for an improved way of utilizing a laser to treat leg veins, telangiectasias and the like without resulting in significant injury to the skin surface.

SUMMARY OF THE INVENTION

In accordance with the above, this invention provides a method for selectively destroying blood vessels contained at a selected depth and in a selected area of a patient's dermis. The method involves the steps of aiming or positioning (hereinafter "positioning") a laser so that light from the laser will impinge upon the selected area of the dermis, and operating the laser to deliver pulsed light to the area, which light has a wavelength of between 700 nm and 1100 nm, with each pulse delivering a fluence at the surface above the area being treated of between 5 joules per square centimeter and 100 joules per square centimeter and each pulse having a pulse duration of between 0.2 milliseconds and 100 milliseconds. The surface area on which the light impinges may for example be between 0.1 square centimeters and 10 square centimeters. The laser may be operated to deliver a single pulse, or multiple pulses may be provided. The laser may also be a continuous-wave laser with pulse duration being controlled by gating the laser to provide the pulsed light, or the laser may be a high repetition rate laser with pulse duration again being controlled by gating the laser. The steps of positioning the laser and operating the laser may be repeated for additional areas of the dermis containing blood vessels to be destroyed until all such blood vessels have been destroyed. During the step of operating the laser, the depth to which vessels are destroyed may be controlled by controlling the fluence delivered by the laser; and the size of the blood vessels to be destroyed may be controlled by controlling the pulse durations.

The blood vessels to be destroyed, and at which the laser is positioned to impinge during the positioning step, may be leg veins, telangiectasias, part of a port wine stain, blood vessels at the base of a hair follicle, blood vessels underlying psoriatic plaque, or other subsurface blood vessels the destruction or elimination of which are desired, either for cosmetic reasons or to alleviate a health condition.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention as illustrated in the accompanying drawings.

IN THE DRAWINGS

Fig. 1 is a sectional diagram of an illustrative skin area containing a hair follicle and blood vessels.

Fig. 2 is a diagram indicating absorption versus wavelength for various components of skin tissue.

Fig. 3a is a diagram of blood vessel temperature rise as a function of vessel depth for a diode laser.

Fig. 3b is a diagram of blood vessel temperature rise as a function of vessel depth for a pulse dye laser.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 illustrates the structure of the outer layers of a person's skin, with the surface epidermis layer 10 normally having a thickness of approximately 100 microns and the underlying dermis layer generally having a thickness of approximately 1.5 to 4 mm. Dermal papillae 12 are formed at the junction between these layers with capillary microvessels 14 being formed for the dermal papillae. Various veins or other blood vessels 18 pass through selected areas of the dermis at selected depths, which depths may vary from less than 1 mm to several mm. Hair follicles 20 may also be formed in the dermis and pass through the epidermis. Each hair follicle terminates in a bulb or papillae which among other things contains blood vessels which nourish the hair follicle.

For various reasons, it may be desirable to destroy the microvessels 14 or, more likely, the veins or other blood vessels 18. For example, the blood vessels 18 may become dilated to form telangiectasias or vascular lesions such as spider veins which, particularly if they occur in facial or leg areas can be cosmetically undesirable. Leg veins, particularly varicose veins, in addition to being cosmetically undesirable, can also be painful. Port wine stains are another cosmetic problem which can be alleviated by removing deep blood vessels. There is research to support the proposition that destruction of the elongated microvessels 14 which are formed under psoriatic plaque can result in alleviation of psoriatic symptoms and it has been suggested that destruction of the blood vessels in the papillary bulb of a hair follicle 20 can sufficiently damage or destroy the hair follicle so as to either prevent of significantly delay the regrowth of hair 22. There are also other conditions for which it may be desirable to destroy a blood vessel deep in the dermis 16.

However, to cause selective thermolysis or heating of blood vessels without collateral damage of surrounding tissues, substantial light energy must get through the epidermis and the dermis above the blood vessel without being excessively scattered or absorbed. However, transmission of light through human skin is largely determined by scattering and by the absorption of the various components within the tissue (e.g., hemoglobin, melanin and water). Fig. 2 is a plot indicating the absorption versus wavelength of tissue components, <u>Lasers in Medical Science Vol. 1,</u> (1986), pp. 47-66. Absorption varies over eight orders of magnitude for wavelengths ranging from 100 nm to 2000 nm. Because water is by far the largest single component of human tissue, the requirement for deep penetration through tissue (to depths of up to several millimeters)

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suggests wavelengths in the 300 nm to 1000 nm range, where water absorption is very low.

At wavelengths shorter that about 700 nm however, the absorption of light by melanin and by hemoglobin causes much of the incident light to be absorbed within a few hundred microns of skin surface. The effort to get sufficient energy to deep vessels at wavelengths shorter than about 700 nm can easily cause explosion of surface vessels and/or burning of the skin. Wavelengths in the 700 nm to 1100 nm range are preferred because skin tissue transmission at these wavelengths is high.

However, achievement of selective photothermolysis of blood in the near infrared region at wavelengths longer than 700 nm has been thought to be unachievable because of the very low absorption coefficient of blood in this wavelength band. At 800 nm, blood absorption is approximately 100 times less that at 577 nm, the typical wavelength used for selective photothermolysis on dermal tissue. Detailed analysis of remittance measurement on human skin however, reveals that absorption in the 700-1100 nm range due to other components of dermal tissue is extremely low. Detailed analysis of light propagation and absorption reveals that energy can be deposited into blood with remarkably high selectivity in the 700 to 1100 nm wavelength region, despite the fact that hemoglobin absorption is very low in this wavelength band. This results from the even lower absorption of other components in this region and also from the fact that the scattering coefficient of tissue in this region is often much lower than in the shorter wavelength visible region.

Therefore, in practicing this invention, a laser is selected which produces light in the 700 -1100 nm wavelength region. Such a laser is preferably a diode laser, for example a commercially available AlGaAs semiconductor diode laser having an output wavelength of approximately 800 nm. However, other diode lasers or other lasers having outputs in the indicated range may also be utilized. Other lasers operating in the desired range include a ruby or other solid state laser or certain continuous wave lasers.

With a semiconductor diode array, a concentrator, which may be a solid or hollow rectangular light guide, may be utilized to direct the array output onto the treatment area, which area may be for example 0.5 cm^2 for certain applications. The treatment area will vary with application from approximately 0.1 cm^2 to 10 cm^2 and should normally be more than 0.4 cm^2 to avoid a significant reduction in local fluence in the tissue due to lateral beam spreading. Other suitable techniques known in the art, including the use of a fiber optic cable and/or applicator, may also be utilized to control the size of the treatment area depending on applications and the laser utilized.

While operating in the wavelength ranges indicated results in a significantly larger percentage of the light energy reaching the deep vessels, there is still some

absorption and scattering of incident light so that there is still a decrease in available energy as the depth increases.

This is illustrated in Fig. 3a which illustrates the blood vessel temperature rise as a function of increased depth for a diode laser operating at 800 nm with an incidence fluence of 17 J/cm^2 and a pulse duration of 5 ms. This can be contrasted with a temperature rise for a pulse dye laser operating at 577 nm and having a fluence of 4 J/cm^2 and a pulse duration of 360 μs, as shown in Fig. 3b. These are typical illumination conditions. The temperatures that are shown reflect the peak vessel temperature that is reached at the end of the laser illumination. Melanin and blood absorption being much lower at 800 nm permits much higher laser powers to be used without causing damage to the epidermis. From the figures the superiority of the longer wavelength for coagulating deep vessels can be seen, the 577 nm laser having an intensity characteristic of exponential absorption and providing high energy down to a depth of only approximately 0.5 mm, with little energy beyond 0.7 mm and essentially none beyond 1 mm. By contrast, at 800 nm light scattering can be much stronger than absorption (in the case illustrated, about a factor of 100x) and the illumination intensity is more characteristic of diffusion. The 800 nm diode laser therefore does not provide high heating at the surface, but continues to provide significant heating in this case, to a depth of approximately 1 mm., and is still providing reasonable heating out to 2 mm and beyond.

If it is assumed that a temperature rise to approximately 60°C is required to coagulate blood, and therefore to destroy a blood vessel, then it can be seen from Fig. 3b that lasers operating in the conventional wavelength can only destroy blood vessels near the surface to a depth of approximately 0.5 mm, while a diode or other laser operating at the longer wavelength (i.e., approximately 800 nm) can, with the fluence shown, destroy blood vessels at approximately up to 1 mm for the case shown. However, if the fluence from the laser is increased, the light energy reaching the deeper vessels will also increase, permitting destruction of blood vessels at depths in excess of 1 mm to depths of 2 mm. In addition, in cases of somewhat lower scattering, heating at depths of several millimeters can be obtained with higher fluence. Such greater depths could for example be achieved with the application of energy of up to perhaps 50 J/cm^2 to the skin surface, with energies of up to 100 J/cm^2 and more being possible for some applications. The danger is that such high energy applied to the surface may cause damage to the skin. However, the low absorption of melanin to the radiation at 800 nm reduces epidermal damage and using a bleaching agent on the epidermis prior to treatment may further reduce the absorption of light by the epidermal layer, permitting higher energy to be utilized without surface damage. Surface damage may also be reduced by either pre-cooling the epidermis in the area to be treated and/or by cooling the epidermis during the application of laser energy thereto. Cooling during the application of the laser energy may for example be accomplished by applying the laser energy through an applicator in contact with the skin which applicator is cooled in

suitable fashion. Where pressure is applied to the applicator, the distance between the surface and the blood vessel to be treated may be reduced and blood in the area between the surface and the vessels to be treated may be removed, permitting deeper blood vessels to be reached with sufficient energy to cause destruction thereof without resulting in significant damage to the epidermal layer.

Another factor which can be controlled is pulse duration. The time duration for illumination should be comparable to or shorter than the thermal relaxation time of the target. The objective is not to have the pulses so long as to cause excessive conduction of heat to tissues surrounding the target; however, since blood is more absorbent than surrounding tissues at the wavelengths being utilized, most of the energy should be absorbed by the blood vessels, permitting relatively long pulses to be utilized. If the pulse width is about equal to the thermal relaxation time of the target vessel, the laser energy may often be more easily generated. In addition, smaller vessels will experience less temperature rise than if a shorter pulse were used. For target blood vessels having a size of approximately 25 to 300 microns, corresponding pulse widths of between 1.0 milliseconds and 30 milliseconds (the pulse width increasing with the size of the vessels) have been found to be suitable. However, for larger blood vessels such as veins, a longer pulse duration, perhaps up to 100 milliseconds, may be desirable. Diode lasers can be operated for any desired pulse duration in the ranges indicated. For a CW laser or a high repetition rate laser, a gating technique, either electronic or optical, may be utilized to achieve the desired pulse width. For example, an optical shutter or mechanical shutter could be utilized to control the duration of the pulse applied to the target area.

While single pulse operation has been discussed above, it is apparent that multiple pulses could be applied to the same area, which pulses are spaced by, for example, one second to as little as 10 ms to assure destruction of the desired blood vessel. Further, since the treatment area is generally relatively small, it may be necessary to adjust the position of the laser, of the target area, of aiming optics for the laser or of an applicator fed by the laser so as to successively treat different relatively small areas until the entire area requiring treatment has been treated. Such repositioning may be done manually or may be accomplished under some type of automatic control.

A method has thus been provided for effectively destroying and eliminating blood vessels in the legs and other parts of the body to treat a variety of cosmetic and medical problems with minimal damage to the overlying epidermis. While specific lasers and techniques for the utilization thereof have been discussed above, specific parameters have been provided above and specific conditions which the method may be utilized to treat have been indicated above, these have been provided for purposes

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of illustration only and other changes in form and detail may be made in the invention by those skilled in the art while still remaining within the spirit and scope of the invention. The invention is therefore only to be limited only by the following claims.